SKRIFTER NR. 176

ØRNULF LAURITZEN

Investigations of Carboniferous and Permian sediments in Svalbard

I. The development of the Gipshuken Formation (Lower Permian) at Trollfuglfjella in Central Spitsbergen, Svalbard

II. The Carboniferous and Permian stratigraphy of the Wahlenbergfjorden area, Nordaustlandet, Svalbard

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DET KONGELIGE MILJØVERNDEPARTEMENT

NORSK POLARINSTITUTT
Rolfstangveien 12, Snarøya, 1330 Oslo Lufthavn, *Norway*

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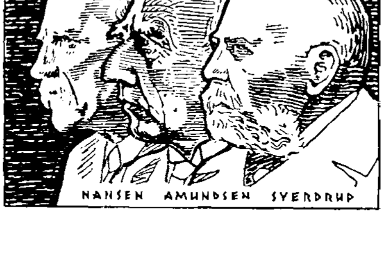

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The development of the Gipshuken Formation (Lower Permian) at Trollfuglfjella in Central Spitsbergen, Svalbard

By ØRNULF LAURITZEN

Abstract

An unusually well exposed 162 m thick continuous section through most of the Gipshuken Formation is seen at Trollfuglfjella north of Isfjorden; this section is here proposed as a hypostratotype for the formation. The Gipshuken Formation consists of interbedded evaporites and dolomites, the evaporites showing highly varied modes of occurrence. Sulphatic beds tend to dominate the lower part of the section, passing up into a dolomite dominated unit. The sediments found reflect deposition in arid lagoonal to supratidal environments, best compared with recent sabkhas. Thin section studies of the carbonate rocks show that algae and algal lamination are important constituents of these carbonates throughout the succession. Even though dolomitization is extensive in most horizons sampled, primary structures can still be seen. About 30 sabkha cycles with interbedded evaporites and dolomites can be distinguished.

Introduction

During Norsk Polarinstitutt's expedition to Svalbard in 1977, I had the opportunity to study the Gipsdalen Group, and the Gipshuken Formation (Cutbill and Challinor 1965) in particular, in the area north of Isfjorden. During the general survey of the area, an extremely well exposed section was found at Trollfuglfjella (Fig. 1). This section was measured in detail and gave new information on the lithology and depositional environments of the Gipshuken Formation's carbonates and evaporites.

The Upper Palaeozoic sediments of this area are almost flat-lying and form table topped mountains; the Gipshuken Formation is present throughout the area, but is usually too poorly exposed to allow detailed study. This formation, previously called the "Upper Gypsiferous Series" by Gee, Harland and McWhae (1953), comprises greyish dolomites interbedded with sulphatic layers or nodules, and according to Cutbill and Challinor (1965) its thickness varies from 211 til 353 metres. These authors defined the formational stratotype on the south-west ridge of Cowantoppen (east of Billefjorden in Bünsow Land). The Gipshuken Formation is assigned to the Artinskian stage of the Lower Permian, a time marked on Svalbard by a general regression. The sediments of this formation suggest mostly widespread shallow marine depositional environments; however, lagoonal to supratidal sabkha environments

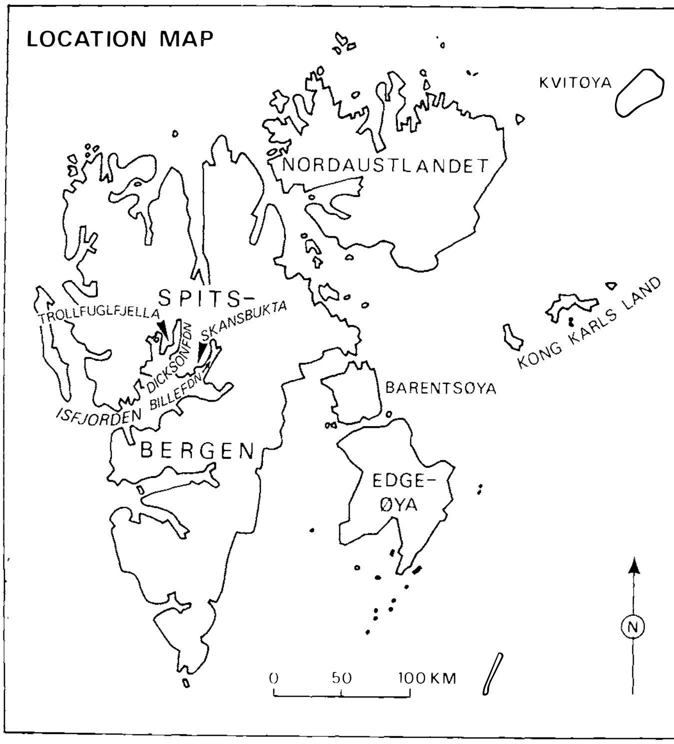


Fig. 1. *Key map to the area, showing the locations mentioned in the text.*

are indicated in areas where gypsiferous beds are developed (e.g. north of Isfjorden).

Several geologists have worked previously in this area and with this part of the succession. However, most published works are of general stratigraphical nature, e.g. Gee et al. (1953), Bates and Schwarzacher (1958), and Cutbill and Challinor (1965). Holliday (1966) described nodular gypsym and anhydrite rocks in the Billefjorden area (Fig. 1), but most of his observations are based on evaporites of Middle Carboniferous age, belonging to the "Lower Gypsiferous Series" of Gee et al. (1953), or to the Ebbadalen Formation and the lower parts of Minkinfjellet Member of Cutbill and Challinor (1965). Holliday (1966) also examined exposures of the Gipshuken Formation at Skansbukta (Fig. 1) in order to compare this unit's evaporites with those of the Middle Carboniferous strata. Lauritzen (1977) suggested a classification of the development patterns of gypsum/anhydrite, based on studies within the Gipshuken Formation in the area north of Isfjorden, but studies at that stage permitted only general interpretations of depositional environments and diagenetic evolution.

Systematic description

The section described here lies on the southeastern slopes of Trollfuglfjella (Fig. 1), facing Dicksonfjorden (a northern arm of Isfjorden). The section is an almost vertical wall of fresh outcrop (Fig 2), permitting unusually detailed

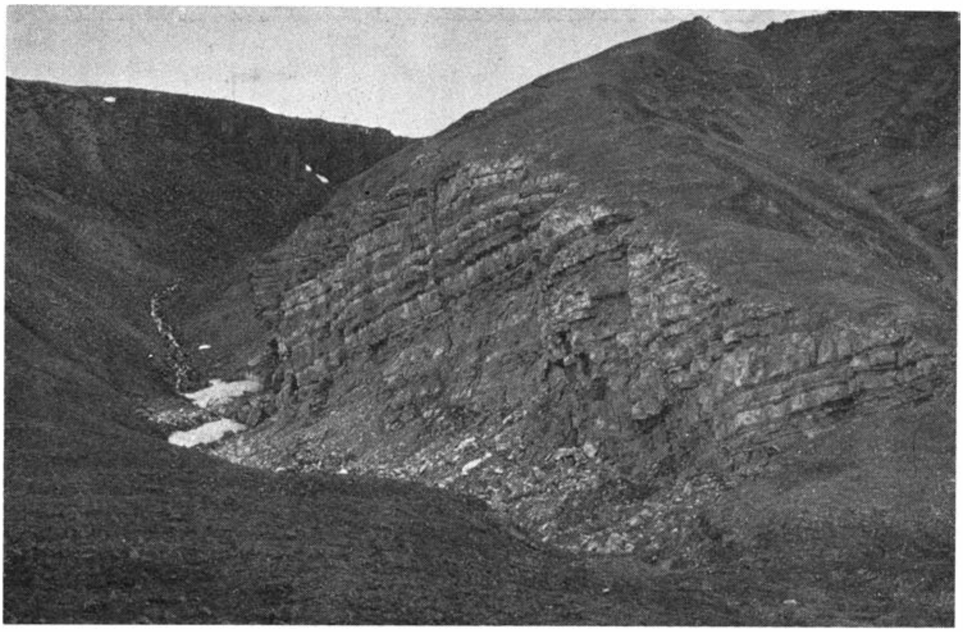


Fig. 2. *The measured section at Trollfuglfjella, as it appears facing Dicksonfjorden.*

sedimentological studies of this otherwise very poorly exposed unit. The Trollfuglfjella section is therefore both more easily accessible and better exposed than the formation's stratotype at Cowantoppen, and hypostratotype status is therefore proposed.

The lowermost beds (90 m above sea level) are interpreted to represent the lowermost part of the Gipshuken Formation. Subsequent work in the Trollfuglfjella area in 1980 support this view (Carl Dons and Mari Skaug, pers.comm.). The succession at Trollfuglfjella terminates upwards against a doleritic sill, but an estimated thickness of the overlying dolomite-dominated part of the sequence of about 40—50 m, gives a total thickness of the Gipshuken Formation of about 210 metres.

The section measured is 162 m thick and displays rapid and often rhythmic changes in lithology between dolomitic and evaporitic dominated units, rhythmicity being most marked in the lower part of the section. Dark shales are of minor importance. Figs. 3 to 7 display the main lithological features and structures observed in field, while more detailed petrographical information based on thin section studies is listed in Table 1.

Sulphates make up about 45% and dolomite about 55% of the total succession, but sulphates are more common in the lower 70 m where they constitute as much as 60% of the section. It is difficult to aduce the precise proportions of these two rock types as each occurs as fine-grained admixtures or impurities within beds dominated by the other. It is, however, obvious from what is seen both here and elsewhere, that these two main constituents in the Gipshuken Formation vary in distribution both vertically and laterally throughout the formation.

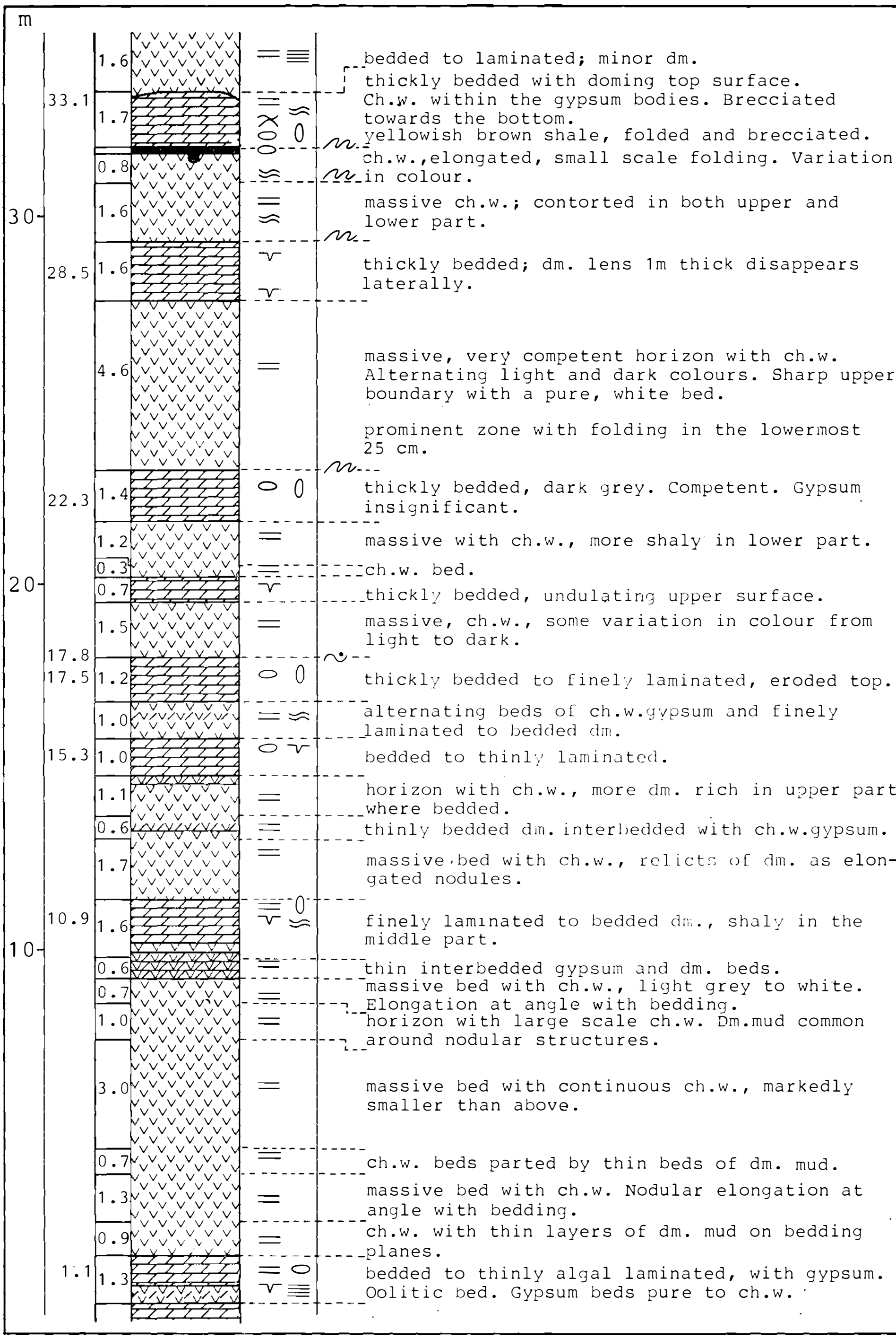


Fig. 3. *A section through the lowermost 35 m of the Gipshuken Formation exposed at Trollfuglfjella. For legend, see Fig. 7.*

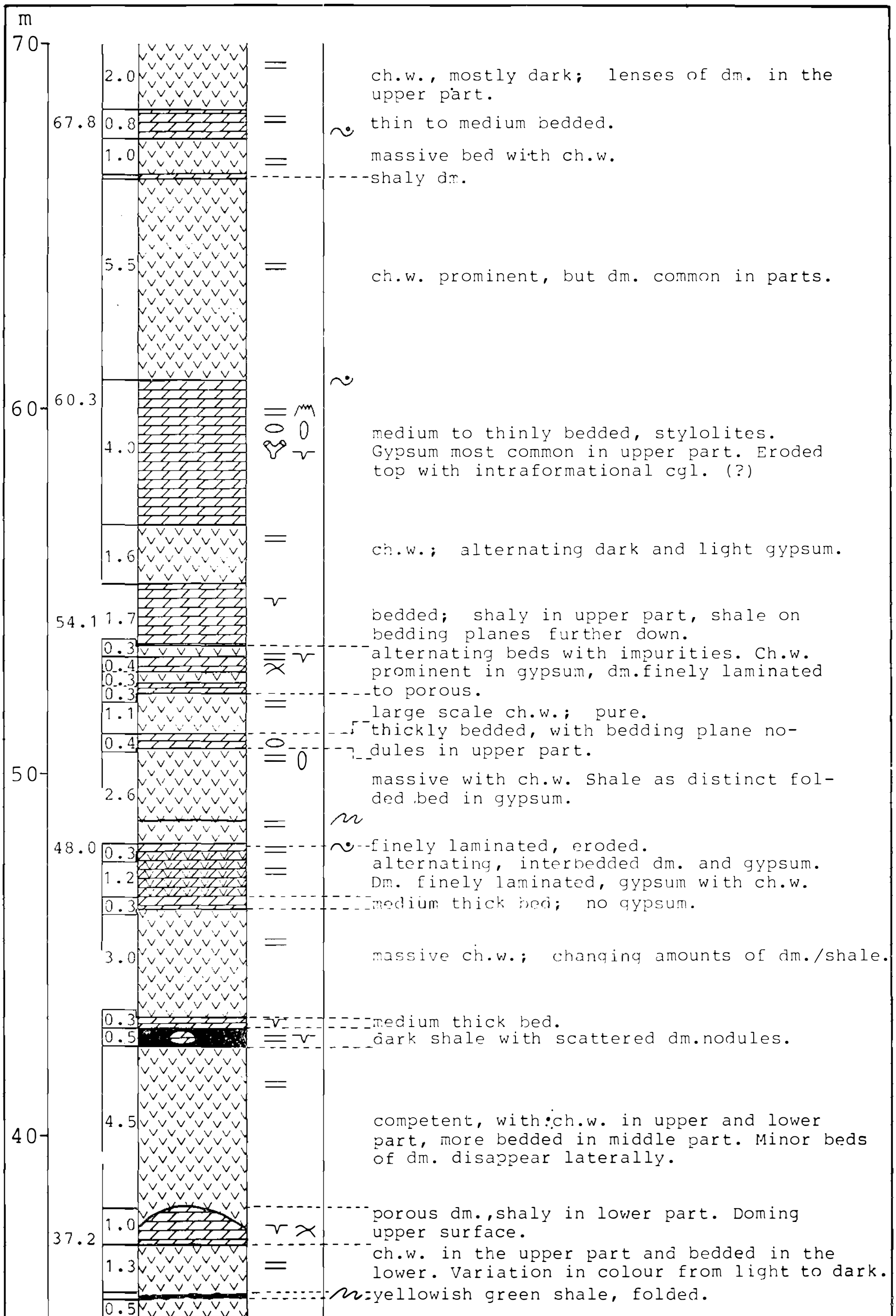


Fig. 4. *The section between 35 m and 70 m of the Gipshuken Formation exposed at Trollfuglfjella. For legend, see Fig. 7.*

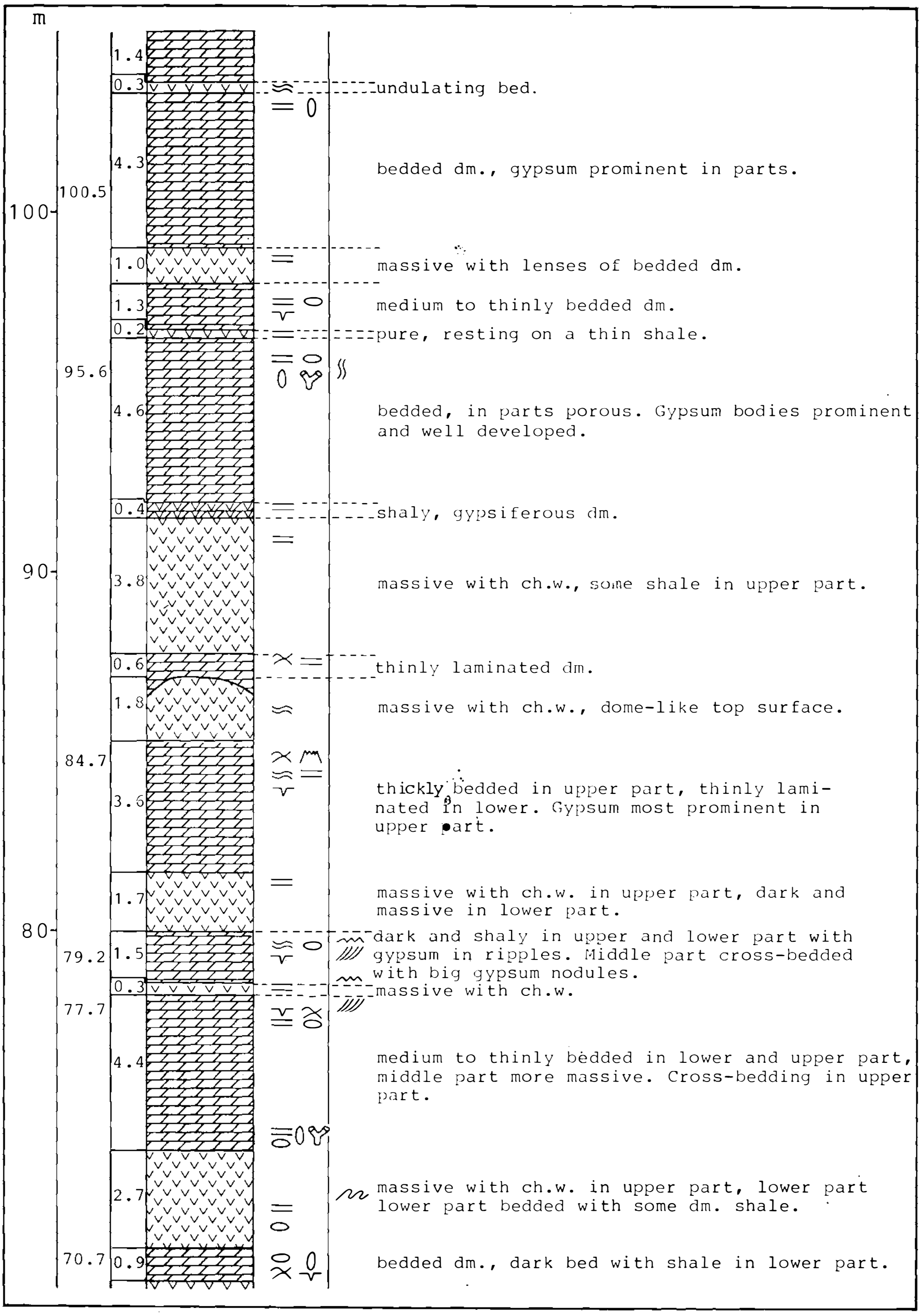


Fig. 5. *The section between 70 m and 105 m of the Gipshuken Formation exposed at Trollfuglfjella. For legend, see Fig. 7.*

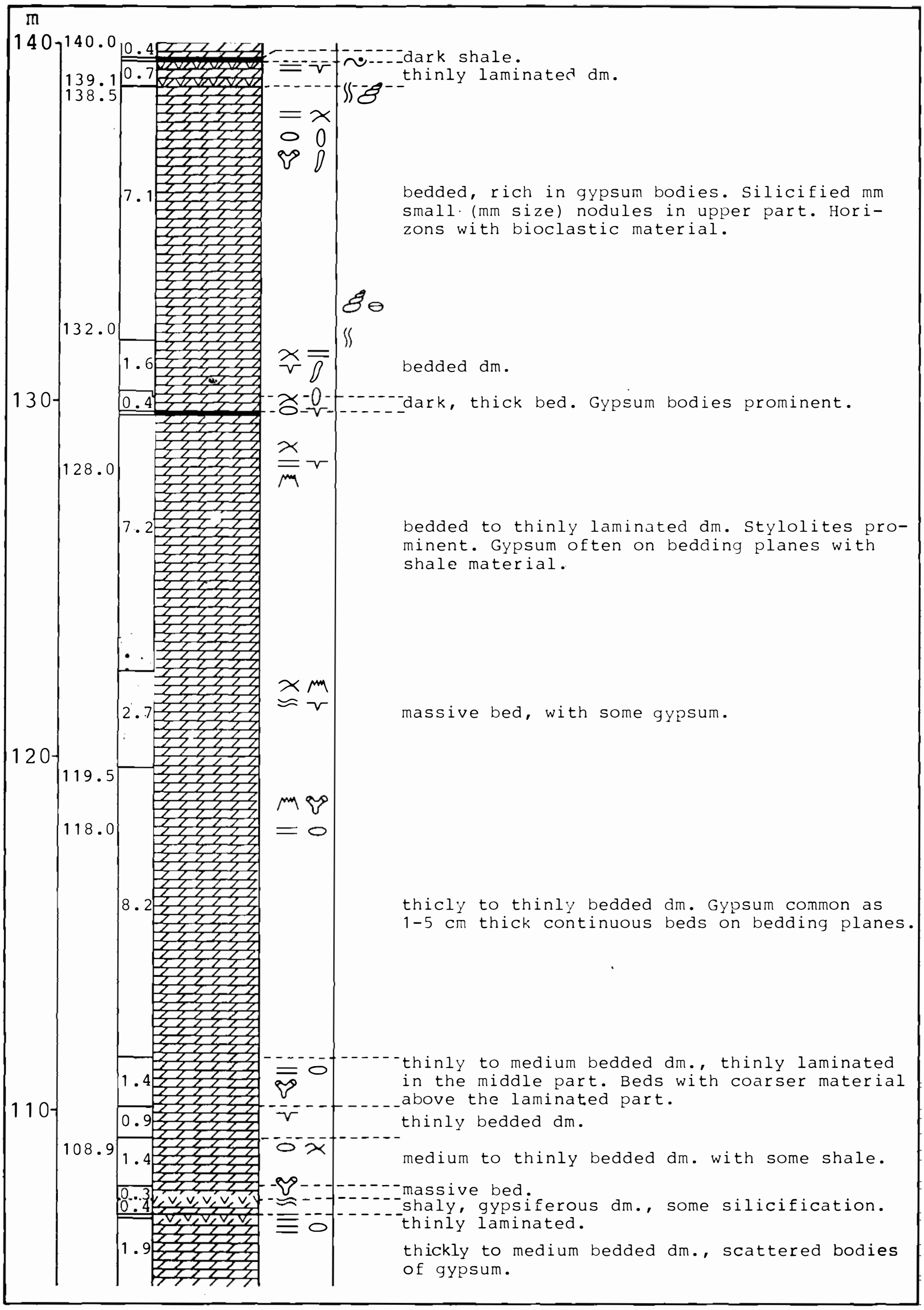
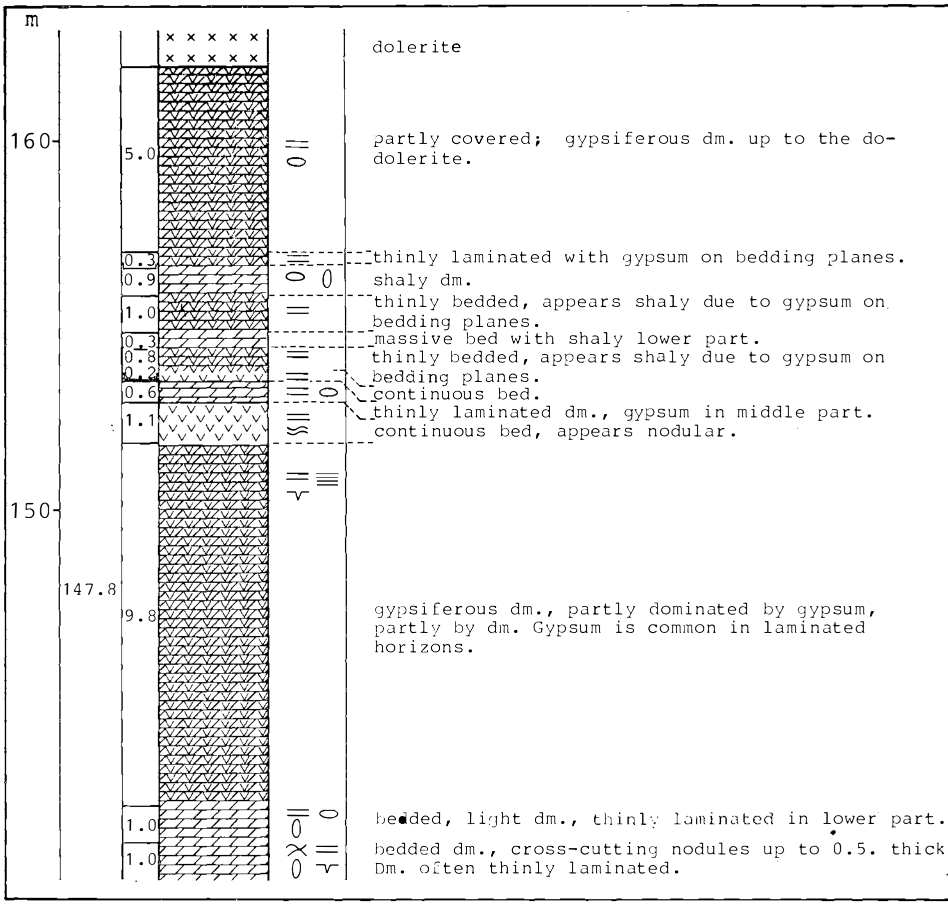


Fig. 6. *The section between 105 m and 140 m of the Gipshuken Formation exposed at Trollfuglfjella. For legend, see Fig 7.*



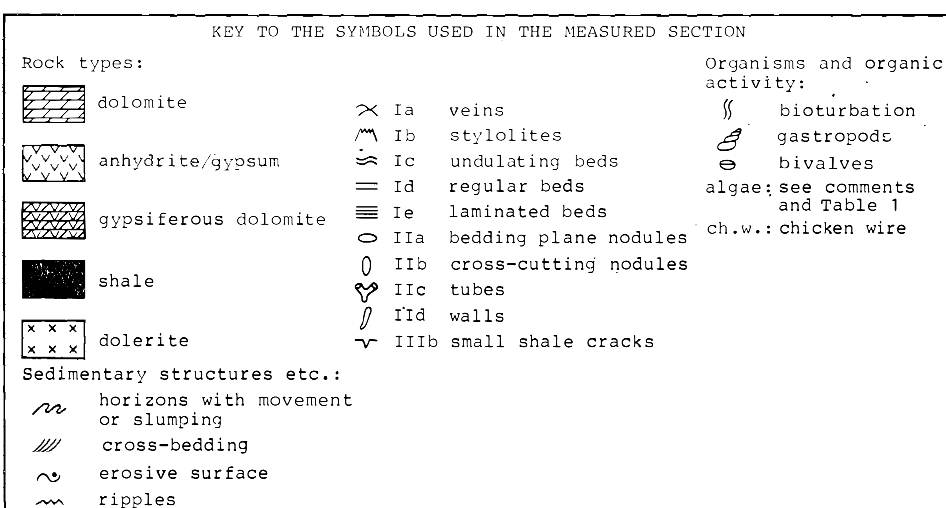


Fig. 7. *The uppermost part, 140 m to 163 m, of the Gipshuken Formation exposed at Trollfuglfjella.*

Sulphatic rocks

The sulphates found in this section are mainly anhydrite and gypsum, but XRD reveals minor amounts of bassanite ($CaSO_4 \cdot 1/2\ H_2O$) and celestite ($SrSO_4$). Some sulphatic material occurs dispersed throughout the dolomites (Table 1), but the bulk of the gypsum/anhydrite present is found in beds of varying shapes and thicknesses, from thin (mm) laminae up to thick (m) massive beds. Lauritzen (1977) reported regular massive evaporitic beds with thicknesses up to 15 metres, but these are not found at Trollfuglfjella, suggesting that the thin dolomite interbeds may possibly be masked by weathering at other localities.

Gypsum and anhydrite occur in many different forms within beds dominated by dolomitic material. These forms, such as nodules or infillings in cracks and fissures, were classified by Lauritzen (1977) in an attempt to standardize the field descriptions of such rocks. This scheme (see legend Fig. 7) is also used here and the symbols are placed in a separate column to the right of the lithology. The system referred to is as follows:

- I *Continuous beds*
  - Ia veins
  - Ib stylolites
  - Ic undulating beds
  - Id regular beds
  - Ie laminated beds
- II *Nodules*
  - IIa bedding plane nodules
  - IIb cross-cutting nodules
  - IIc tubes
  - IId walls
- III *Cracks and fissure infillings*
  - IIIa megafissures
  - IIIb small scale cracks
- IV *Fossil infillings*
- V *Crystals*

The colour of the sulphatic beds is highly variable from almost pure white through most grades of grey to almost black. The variation in colour is caused by differing amounts of impurities (mainly dolomitic material), and this content of dolomite is fully shown in the beds with chickenwire structure.

The evaporites exposed today consist of partially gypsified anhydrite within a hostrock of dolomite. Anhydrite is the dominant subsurface mineral in this area, and was mined in Skansbukta in 1918. The mining soon stopped as more and more anhydrite was encountered at depth. Gypsum is, however, found more or less as crusts on outcrops and in shallow subsurface, and the occurrence of basanite should indicate that gypsification is still an active process. The area is today subjected to permafrost, and water does not circulate in the subsurface as it does in more temperate areas.

Table 1.

Microfacies analyses of samples from the Gipshuken Formation at Trollfuglfjella. Abbreviations: micr. (micrite), sp./rh. (sparry cement or rhombs), calc. (calcite), anhy. or gyps. (anhydrite or gypsum), part. (partially), silic. (silicified), gyp. (gypsified.)

Sample ØL 77/ TFF	Rock type	Textural components (%)											Comments
		dolomite			calc.	quartz		anhy. or gyps.	skeletal grains			pores	
		total	micr.	sp/rh		grains	chert		total	algae	indet		
147.8	dolomitized biomicrite	92	92		< 1	2			4*				*) Microcodium
140.0	dolomitized intra-algal micrite	90	90		9	1			62	62			calc. as sparry cement
139.1	dolomitized algal micrite	97	97		2	< 1			42	40	2		sparry calc. in cracks
138.5	dolomitized part.silic.biomicrite	72	72		2		26		28		28*		*) most fossils silicified
132.0	dolomitized algal micrite	90	90						25	25		10	dolomoldic porosity
128.0	part. dolomitized biomicrite	74			23	3			30	7	23*		*)mostly Microcodium
119.5	dolomitized algal micrite	91	91			4		5		*			*)algae as micrite
118.0	dolomicrite	99	97	2		< 1							some bitumen
108.9	dolomite	78		78	9	5		4				3	
100.5	dolomicrite	99	99			< 1							
95.6	dolomicrite	97	97			3			< 1		< 1		
84.7	part.gyp. dolomitized oosparite	61	61*					36				3	*) mostly ooids and grains
79.2	part.gyp. dolomitized oosparite	50	27	23				50					cross-bedded
77.7	part.gyp. dolomitized oosparite	26		25*				74					*) mostly micro-spar
70.7	part.gyp. dolomicrite	70	70					30					poikilitic anhydrite
67.8	dolomicrite	88	88			< 1	< 1	9				2	poikilitic anhydrite
60.3	part.gyp. dolomitized oosparite	48	48*					52					*) mostly grains
54.1	part.gyp. dolomicrite	74	74			< 1		25					poikilitic anhydrite
48.0	part.gyp. dolomicrite	69	69			8		20	3	3			
37.2	part.gyp. dolomicrite	40	40					55				5	
33.1	part.gyp. dolomicrite	54	54			< 1		43				2	fracture porosity
28.5	part.gyp. dolomitized biomicrite	89	86	3		1		10	13	3	10		
22.3	part.gyp. silty dolomicrite	62	62			10		28					
17.8	part.gyp. dolomicrite	48	48			1		51					
17.5	dolomitized part.silic. biomicrite	77	77			< 1	22		22		22*		*) some are gastropods
15.3	part.gyp.silty dolomicrite	70	70			20		10					
10.9	part.gyp.silty dolomicrite	54	54			21		25					
1.1	part.gyp. dolomitized oosparite	79	54*	26				21					*)mostly ooids and grains

Carbonate rocks

The carbonate rocks are completely dominated by dolomites, and most rocks contain no other carbonate mineral. However, small quantities of calcite are found, restricted to the upper part of the section (see Table 1), but even here only three samples contain more than minor amounts of calcite. The carbonate rocks have mostly micritic texture, and dolosparites or coarsely crystalline dolomites are rare. Most consist of dolomitized micrites, here called dolomicrites, which are interpreted as having been originally pure micrites or biomicrites. Algal textures are common in this section, and will give the classification algal micrite. The dolomitic rocks sampled contain on average 73% dolomite, ranging from 26% to 99%.

The most important non-carbonate minerals in the dolomitic rocks are, however, anhydrite and gypsum; these minerals are often difficult to distinguish from each other, and are therefore here presented as one column in Table 1. Eighteen (of twenty-eight) carbonate samples contain on average 30% evaporite minerals (ranging from 4% to 74%). A high content of evaporite minerals is most frequent in the lower part of the section which is dominated by sulphatic beds. These relatively high contents are unexpected in view of the field appearance of these carbonates.

Quartz grains are found in a majority of the samples, but only three of them contain 10% or more (TFF 10.9, TFF 15.3, and TFF 22.3). The quartz grains, which are mainly of silt size, tend to be most common in the lower part of the section, and only one 15 m thick horizon (from 70 to 85 metres above the base of the section) is almost free of quartz; this unit also displays cross-bedding (see Fig. 5).

Cherts are also found in parts of the section, especially in fossiliferous beds where they have replaced the original fossil shells. Chert also occurs sporadically in the more shaly dolomites.

Even though dolomitization has been extensive and has undoubtedly destroyed some of the primary features of the rocks, many of the samples clearly exhibit textural features, which are here used as keys to the understanding of the rocks. These properties, exhibited in Table 1, reveal some of the primary features prior to dolomitization. Only one sample (TFF 108.9) is here presented as a dolomite, with no other distinguishable properties. Based on thin section studies, four lithofacies can be distinguished.

Lithofacies A: *dolomicrite;* micro- to cryptogranular mud, often with microspheres of anhydrite (can be misinterpreted as pellets or ooids in field). These small poikilitic anhydrite spheres contain dispersed microgranular dolomite, as found in the host rock. Even though each of the spheres is found to represent an anhydrite crystal, an outer rim of gypsum is found in some of the spheres, now in crystallographic continuity with the anhydrite. Such microspheres of anhydrite are found scattered in the dolomite hostrock or as clusters. Microscopic cracks filled with anhydrite set through the rock (see Pl. 1, 1 and 5).

Lithofacies B: *silty dolomicrite;* the carbonate is totally dolomitized and appears mostly cryptogranular. Quartz silt is found dispersed through the whole rock, but also accumulates on bedding planes (often with bitumen). Sulphate is found in nodules and small cracks (see Pl. 1, 2).

Lithofacies C: *dolomitized algal micrite;* mostly thinly laminated algal beds, now totally replaced by dolomite. Often "coarser" grains between the laminae. Algae also found as lumps. Sulphate is common. (Pl. 1, 3).

Lithofacies D: *dolomitized oosparite;* ooids as well as bioclastic grains, completely replaced by dolomite, the interparticle and oomoldic porosity infilled by sulphate. The outer surface of the ooids now covered with a rim of dolomite crystals, replacing small aragonite needles. This grain supported rock is also found heavily anhydritized, and the primary features are only seen as ghosts in the now sulphatic rock. Sedimentary structures such as ripples and cross-bedding reveal some current or wave energy during deposition. (see Pl. 1, 4 and 6).

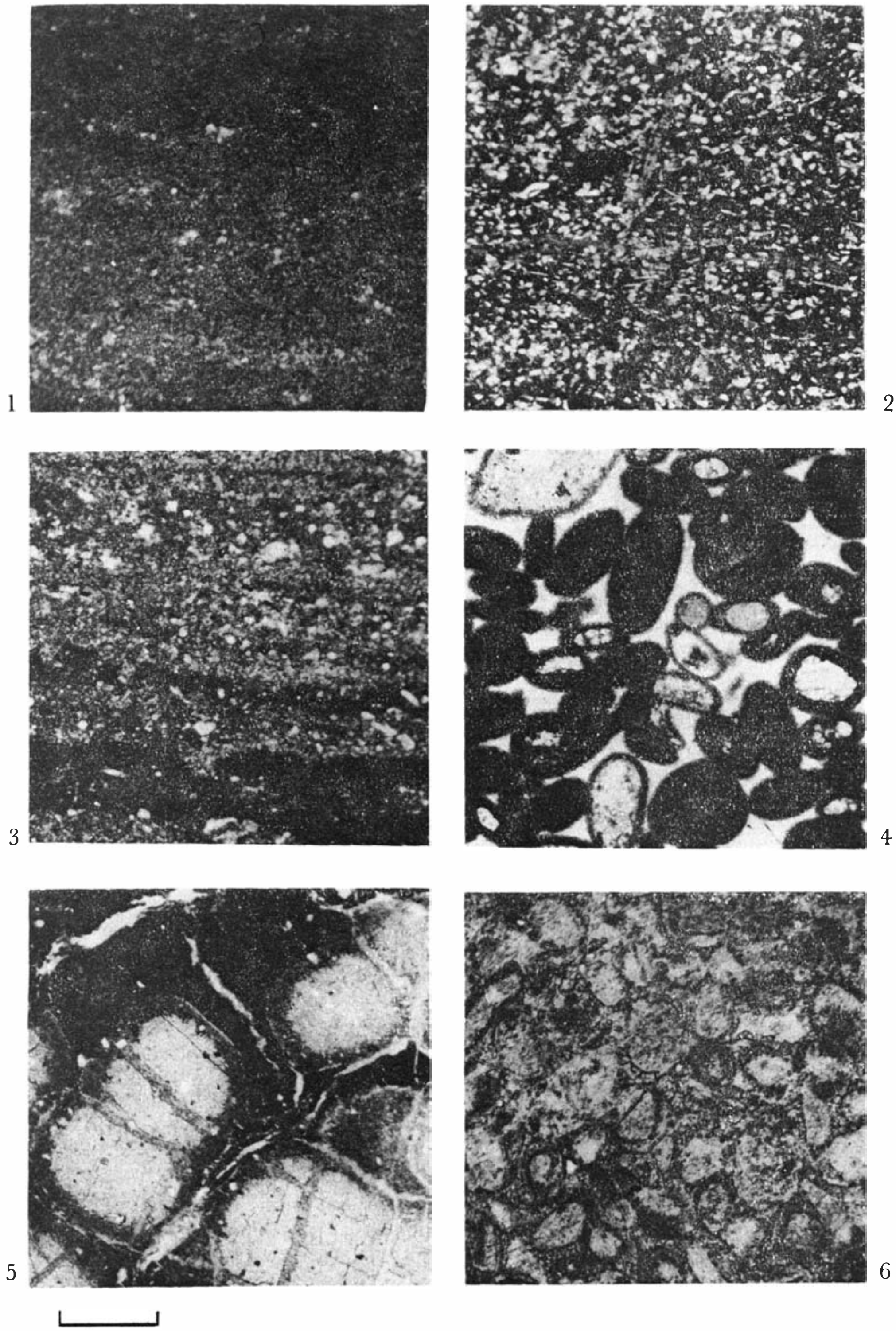
Shelly fossils are rare. However, gastropods are seen in thin section (TFF 17.5) from the lower part of the succession, and gastropods and bivalves can be observed in the field in the upper part (levels 132 and 139 in Fig. 6). These finds could explain the occurrence of pelloidlike grains observed in some of the samples collected, although they are not common. A little bioturbation is also found at certain horizons.

Algae have been positively identified in seven of the samples studied, and from thin section studies one can see that thinly laminated algal micrites tend to dominate in the upper part of the section at Trollfuglfjella, a tendency clearly indicated in Table 1. The algal tissues are now totally replaced, and only ghosts are seen in the dolomitized sediments. There are, however, thinly laminated dolomicrites throughout the succession, and the majority of these should be classified as algal micrites.

Another prominent feature observed in thin section from the upper part of the succession is *Microcodium,* here found in two samples (TFF 128.0 and TFF 147.8). Klappa (1978) describes occurrences of *Microcodium* in palaeosols, and this has clear environmental implications for the present work.

PLATE 1. →

1. Lithofacies A; dolomicrite, as it appears in sample TFF 100.5
2. Lithofacies B; silty dolomicrite. Sample TFF 15.3
3. Lithofacies C; dolomitized algal micrite, finely laminated as seen in sample TFF 139.1
4. Lithofacies D; dolomitized oosparite. Sample TFF 1.1
5. Lithofacies A; here partly sulphatic, with clusters of anhydrites spheres. Sample TFF 33.1
6. Lithofacies D; oosparite, here heavily sulphatized. Sample TFF 77.7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One of the most striking features of this section is the rhythmicity in the interbedding of dolomite and anhydrite throughout the lowermost 100 metres. This rhythmicity has been observed by previous workers in the area, but the causes for this phenomenon have not been discussed previously. Within the lowermost 100 metres of the succession are found about thirty prominent beds of anhydrite (see Figs. 3—5) of varying thickness interbedded with dolomites, and closer inspection shows that even within the beds here described as separate units, different subunits can be distinguished.

Some erosive surfaces and contorted beds are found within the succession (see Figs. 3—7), but because of extensive secondary processes in connection with the sulphate beds, there are limits to what can be observed of primary properties.

Discussion

The Gipshuken Formation has perhaps been less studied than the over- and underlying units, because of its complex diagenesis and apparent absence of fossils and primary sedimentary structures.

Many works on evaporites have been published in recent years from the Trucial Coast of the Persian Gulf, where the sabkha model finds its roots. These works from the early 1960's and the discovery of primary anhydrite in the salt-flats (Curtis et al. 1963) initiated new investigations on both modern and ancient evaporites, and these can also be used to shed new light upon the deposition of the Gipshuken Formation of Svalbard.

In the studied section, algal laminae, primary bioclastic material, and sedimentary structures are found. The upper dolomitic part of the succession is dominated by micro- to cryptograined micritic sediments, here assigned to lithofacies A, B, and C (see Pl. 1, 1—3). They indicate quiet depositional environments as found in lagoonal areas. It is within this environment that thinly laminated algal mats are found, and their total thickness varies from just a few centimetres to several metres. The mucilaginous blue-green algae trap and bind the mud on their surface, but do not secrete any calcareous skeletons of their own.

Grain-supported sediments are assigned to lithofacies D (see Pl. 1, 4), a rock type which reflect deposition in agitated environments, as found in border areas of lagoons or in channels cutting such. The replaced aragonite needles, as observed in lithofacies D, suggest lower intertidal or submarine cement, which again indicates the environment.

The term sabkha has not previously been used in the literature in connection with the Gipshuken Formation, though Nysæther (1973, p. 34) indicated a lagoonal or/and supratidal environment for the carbonates and anhydrites in similar beds in Torell Land, southern Spitsbergen. It is now believed that the Gipshuken Formation in Central Spitsbergen represents such an environment and the section from Trollfuglfjella will critically be examined in relation to sabkha models.

About 30 rhythms with anhydrite are found in the lowermost 100 m of the

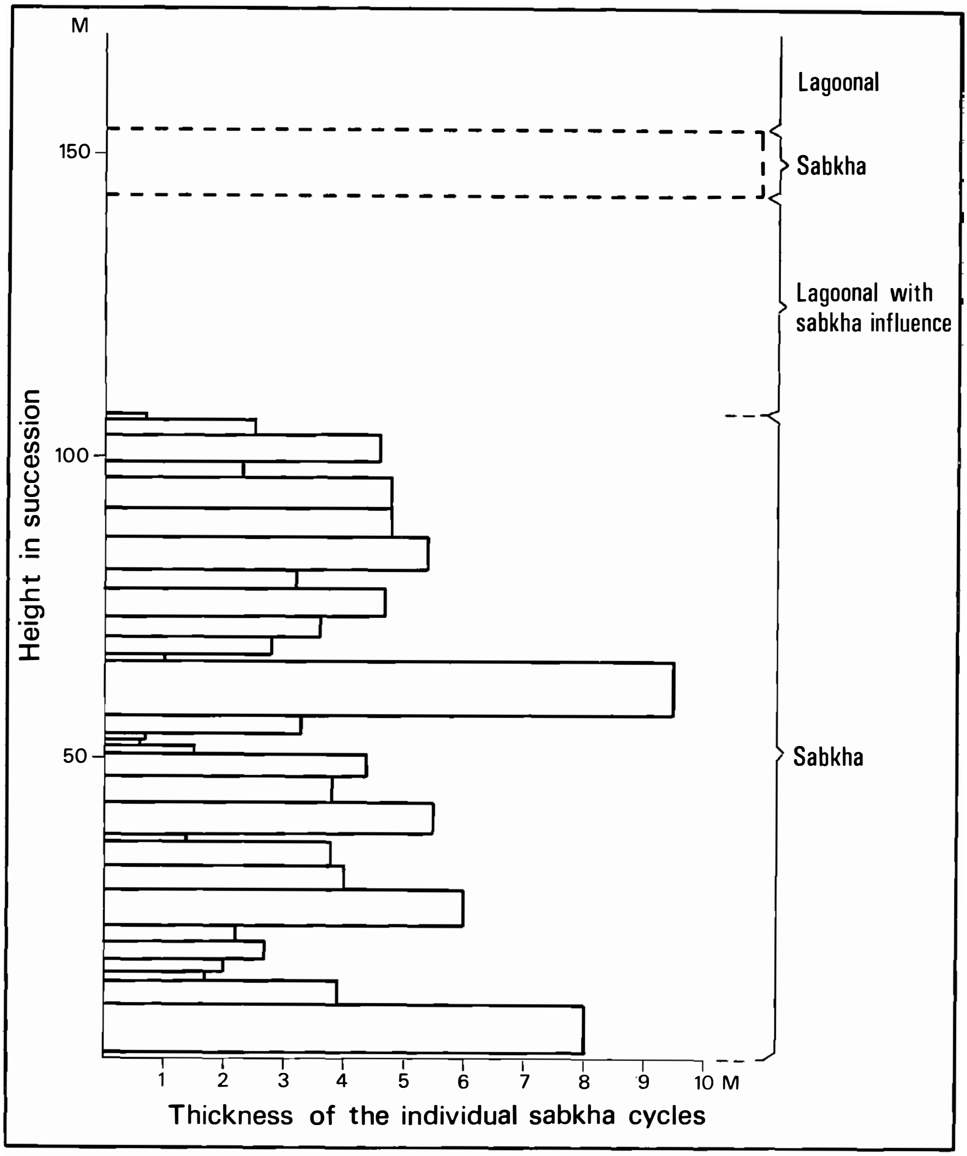

Fig. 8. *About 30 sabkha cycles are distinguished throughout the succession at Trollfuglfjella, varying in thickness from 0.6 to 9.5 m.*

section at Trollfuglfjella (Fig 8), varying in thickness from 0.6 to about 9.5 metres. These resemble the sabkha cycles described by Kendall (1979); each rhythm starts with a carbonate unit followed by carbonates with anhydrite nodules, ending with chicken wire anhydrite and commonly terminated upwards by a sharp erosive contact to the next cycle. Such erosive surfaces are neither numerous nor well developed in this section, but are found on certain bedding planes. However, in the Skansbukta area further east (Fig. 1), there is large scale erosion of one of these major evaporite beds (Lauritzen in prep.).

The rhythmicity in the Gipshuken Formation at Trollfuglfjella is therefore interpreted in terms of stacked sabkha cycles. It is evident from the succession that marine flooding took place, probably both as a result of storms and relative sea-level changes, resulting in the formation of erosive surfaces and ripples. Cross-bedded horizons, indicating stronger currents, probably represent channels within the lagoonal area. The oolitic beds are also interpreted to be channel infillings or nearshore bars.

Dolomitization is almost complete in the carbonate rocks of this succession, and this is thought to be the result of early diagenetic processes, a feature which is characteristic for supratidal coastal sabkhas (Kinsman 1969). Once shoreline regression occurs, evaporitic minerals are deposited in the upper part of the marine wedge, and dolomitization of the fine-grained carbonate sediments takes place. In this process calcium ions are released, and thus additional gypsum or anhydrite precipitates from the interstitial pore fluids. The quartz grains which are found in the lower part of the Trollfuglfjella section, are supposed to originate from a hinterland, transported onto the sabkha flats by wind.

The sulphate in this section is represented by a number of differently formed bodies (Lauritzen 1977), and is found dispersed in the dolomites themselves. The algal laminated sediments in some cases contain thin layers of sulphates between the algal laminae. These sulphatic layers are suggested to originate, at least in part, by secondary replacement of gypsum, which again was originally present in the upper algal mat zone (c.f. Butler 1970). These original gypsum crystals are pseudomorphed by anhydrite, and in some cases subsequent precipitation of anhydrite has resulted in disruption of the pseudomorphed crystals and formation of anhydritic nodules.

Celestite, which is found in some samples, is often associated with early supratidal diagenesis, and the Sr is thought to be released from aragonite. This aragonite, which is replaced in sample TFF 1.1 (and the other oolitic rocks), could suggest lower intertidal or submarine cement, which is later altered by supratidal diagenetic processes.

Structures are observed in this section which suggest that the sequence has been subjected to minor disturbances; some beds show small folds or contorted layers. More shaly horizons with signs of movements are also found within the unit, but none of these movements appear to have been of any great significance, though they are supposed to have been the result of later orogenetic activity in the nearby Tertiary deformation zone.

Summary

The Gipshuken Formation, as it appears north of Isfjorden, contains stacked sabkha cycles, suggesting alternation of regressive periods with formation of evaporites with periods of intertidal deposition. These characteristic features suggest that coastal sabkhas were developed in this area during parts of the Artinskian stage of the Lower Permian system, and that these environments

were maintained for a considerable time, producing the deposition of a substantial thickness of evaporitic dominated sediments.

There are also nodules and thin beds of evaporites in the upper part of the studied section, though they are not dominant here. These evaporites represent shorter sabkha events in a more marine influenced environment. The lithology which is mainly dolomicritic, displays algal lamination as found in lagoons, but open marine carbonates with corals are also found.

More open marine depositional environments are also seen elsewhere in the upper part of the Gipshuken Formation (e.g. Nordaustlandet, Lauritzen 1981). These perhaps mark the termination of the large scale regressive trend from the Sakmarian, and presage the general transgression which took place in the Kungurian and Upper Permian, resulting in the deposition of the Kapp Starostin Formation.

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The Carboniferous and Permian stratigraphy of the Wahlenbergfjorden area, Nordaustlandet, Svalbard

By Ørnulf Lauritzen

Abstract

A relatively complete section through the Carboniferous and Permian sediments of the Wahlenbergfjorden area of Nordaustlandet is presented. The 412 m thick succession comprises the Nordenskiöldbreen, Gipshuken and Kapp Starostin Formations of Upper Moscovian to Upper Permian age, overlain by Triassic silty shales. The Upper Palaeozoic sediments in this area rest with a distinct angular unconformity on folded and eroded Hecla Hoek rocks.

Both the Nordenskiöldbreen and Gipshuken Formations are characterised by carbonate rocks, although conglomeratic and quartzitic interbeds are also found. Indications of primary evaporites are found at certain horizons. The Kapp Starostin Formation is dominated by silicified rocks, although limestones are abundant. New members are introduced within all three formations in the Wahlenbergfjorden area, and the area can now better be correlated with the well-known equivalent units of central Spitsbergen.

Introduction

During Norsk Polarinstitutt's expeditions in 1978 and 1979, I investigated the Upper Palaeozoic sedimentary succession in the Wahlenbergfjorden area of Nordaustlandet (Fig. 1). The purpose of this paper is to describe the stratigraphy of the Upper Palaeozoic sediments of this area, and to introduce new evidence for the age of these sediments. The paper will also introduce new stratigraphical units, and correlate the succession with corresponding sequences from the Lomfjorden area and from the more well-known areas in the central parts of Spitsbergen.

The succession on Nordaustlandet had been studied previously by several geologists, but the lack of good exposures and fossil material still left many questions unanswered. Present knowledge on the stratigraphy is based on works by De Geer (1923), Sandford (1926, 1950, 1956, and 1963), Kulling (1934), Holland (1961), and Lowell (1968). Some of these papers were used by Cutbill and Challinor (1965) in their revised stratigraphical scheme for the Carboniferous and Permian rocks of Svalbard, a scheme also used in this paper as a framework for my own studies. New palaeontological and sedimentological evidence has, however, made it necessary to revise their scheme for Nordaustlandet (Fig. 2).

Description of the area

The mountains around Wahlenbergfjorden, where almost flat-lying Upper Palaeozoic sediments are preserved, have a very characteristic table-top form. The sediments are capped by doleritic sills on some of the mountains (e.g. Idunfjellet and Zeipelfjella).

Folded and eroded Hecla Hoek sediments occur below the flat-lying Upper Palaeozoic succession, and the boundary between these rock units was described by Hollin (in Sandford 1963), from Idunfjellet north of Wahlenbergfjorden, an observation also found on the geological map by Flood et al. (1969). Sandford (1963, p. 20) states that "the abraded surface of Hecla Hoek may lie fairly close to sea level along the southern side of Wahlenbergfjorden". The Hecla Hoek is now shown to be exposed, along the southern side of the fjord. At Hårbardbreen, where Lowell (1968) measured one of his sections, a folded reddish mudstone is found up to about 30 m above sea level, and at Ismåsestranda further west, the lowermost part of the section contains this same red mudstone. At Ismåsestranda, the mudstone is flat-lying, and could be taken as belonging to the Upper Palaeozoic sequence, while at Hårbardbreen it is folded, thus showing a marked angular unconformity and erosive contact with the overlying conglomeratic and quartzitic beds. As Lowell clearly included some of the Hecla Hoek in the Upper Palaeozoic succession in his Hardbardbreen Member, a redefinition of this lowermost unit is necessary.

All exposures in the area are restricted to a narrow strip of land between the sea and the inland glaciers. Besides the Upper Palaeozoic sediments, there are scattered outcrops of Triassic silty shales in the investigated area (Fig. 1).

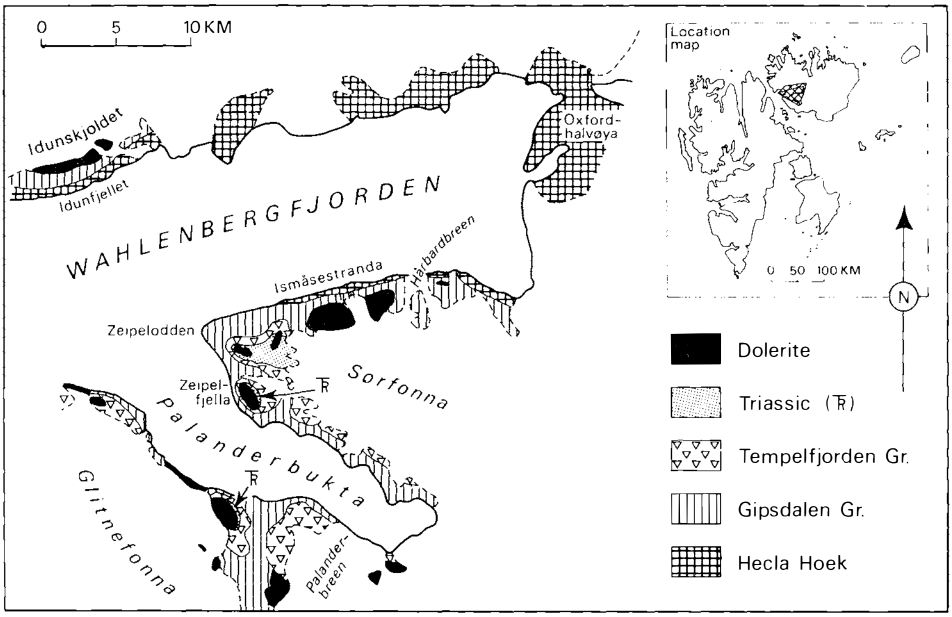

Fig. 1. *Geological map of the investigated area around Wahlenbergfjorden, with a key map to the area.*

These outcrops are, however, of minor importance, but give an excellent control of the Permian-Triassic boundary.

The sections measured were chosen in order to give as complete a description as possible of the Upper Palaeozoic succession in the area. Idunfjellet is the only mountain north of Wahlenbergfjorden were parts of this succession are exposed. Earlier authors (Sandford 1963 and Lowell 1968) claim that Idunfjellet has only few and bad exposures, and I therefore went over the entire area. On this survey, I did not observe sediments above the dolerite sill, such at noted by Sandford (1963, p. 19). However, Sandford (1926, p. 644) merely stated that: "Loose blocks of the latter (i.e. silicified limestone) occur above the sill". The loose material of sedimentary origin that I registered was mostly ice transported dolomites and cherts.

The most complete section at Idunfjellet (Fig. 3) is found in the eastern part of the mountain, along the southern escarpment, where 150 metres of sediments above the Hecla Hoek were measured, terminated upwards by a dolerite. Only two intervals in this section, comprising 24 metres, were covered or partly covered by scree. The boundary between the Upper Palaeozoic and the underlying Hecla Hoek is exposed at this locality, the Hecla Hoek here being represented by a reddish, shaly mudstone. The angular unconformity which is so distinct along the southern escarpment of Idunfjellet cannot be seen at this locality. The contact is apparently conformable, probably because the Upper Palaeozoic overlies a small anticlinal crest in the Hecla Hoek.

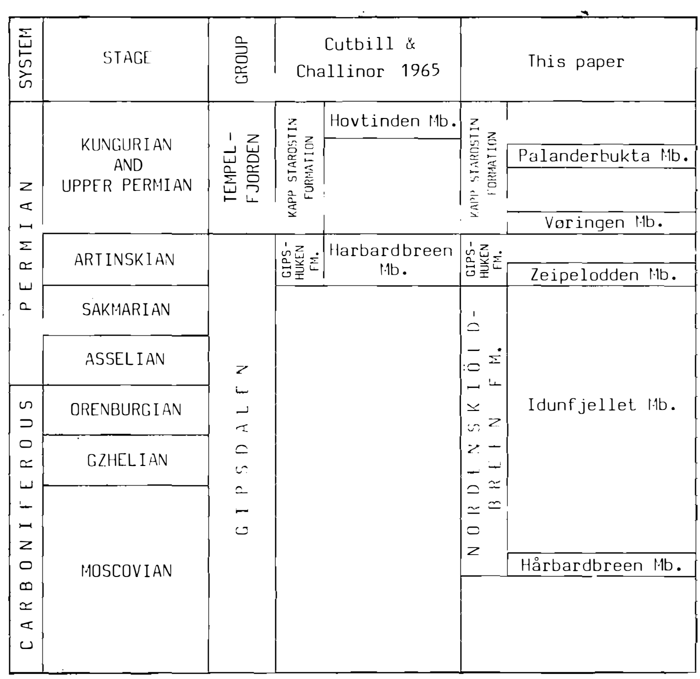

Fig. 2. *Stratigraphical scheme for Nordaustlandet.*

Upper Palaeozoic sediments comprise most exposures south of Wahlenbergfjorden, although both Hecla Hoek and Triassic beds are also found. The area was carefully examined before sections were measured. The mountain sides are heavily covered by scree, but important sections were found at Zeipelodden and Zeipelfjella (Fig. 1). I also visited the section at Hårbardbreen for comparison with Lowell (1968), but exposures were too poor for a detailed study. My observations from this section are, however, incorporated with the other information from the area.

Stratigraphy

The outcrops studied are assigned to the formations defined by Cutbill and Challinor (1965) for central Spitsbergen. They interpreted the basal units on Nordaustlandet as belonging to the Gipshuken Formation (Fig. 2). However, a 150 m thick sequence occurs under typical Gipshuken Formation sediments, a sequence which is similar to the Nordenskiöldbreen Formation with the Hårbardbreen Member at its base. New fossil finds from the base of this sequence at Idunfjellet suggest an Upper Moscovian age for the beds immediately above the Hårbardbreen Member.

NORDENSKIÖLDBREEN FORMATION

Type section: Idunfjellet

Reference sections: Zeipelfjella

The formation is 150 m thick, and two members can be distinguished, a lower Hårbardbreen Member and an upper Idunfjellet Member. The formation is best exposed at Idunfjellet (Fig. 3), although the upper part is better exposed at Zeipelfjella south (Fig. 4).

Hårbardbreen Member

Type section: as for formation

The member (called Harbardbreen in English literature) is 15.5 m thick at Idunfjellet. It is very well exposed, starting with an 8 m thick conglomerate. The conglomerate at Idunfjellet contains mostly clasts of dolomitic mudstones (Table 1, sample ØL 78/14), although material from the underlying red Hecla Hoek mudstone is also common. The conglomerate is also apparently stained from the red sediment below. Kaolinite is found as millimetre large, white patches in the rock.

A 7.5 m thick, light yellowish-grey quartzitic sandstone overlies the conglomerate. This sandstone, which is normally fine-grained to medium-grained (Table 1, sample ØL 78/15) contains some conglomeratic horizons. Cross-bedding is seen in some beds, and the whole unit forms a fining-upwards sequence.

The lack of the dolomitic conglomerate on the southern side of Wahlenbergfjorden, and a 14 m thick sandstone in the western part of Idunfjellet,

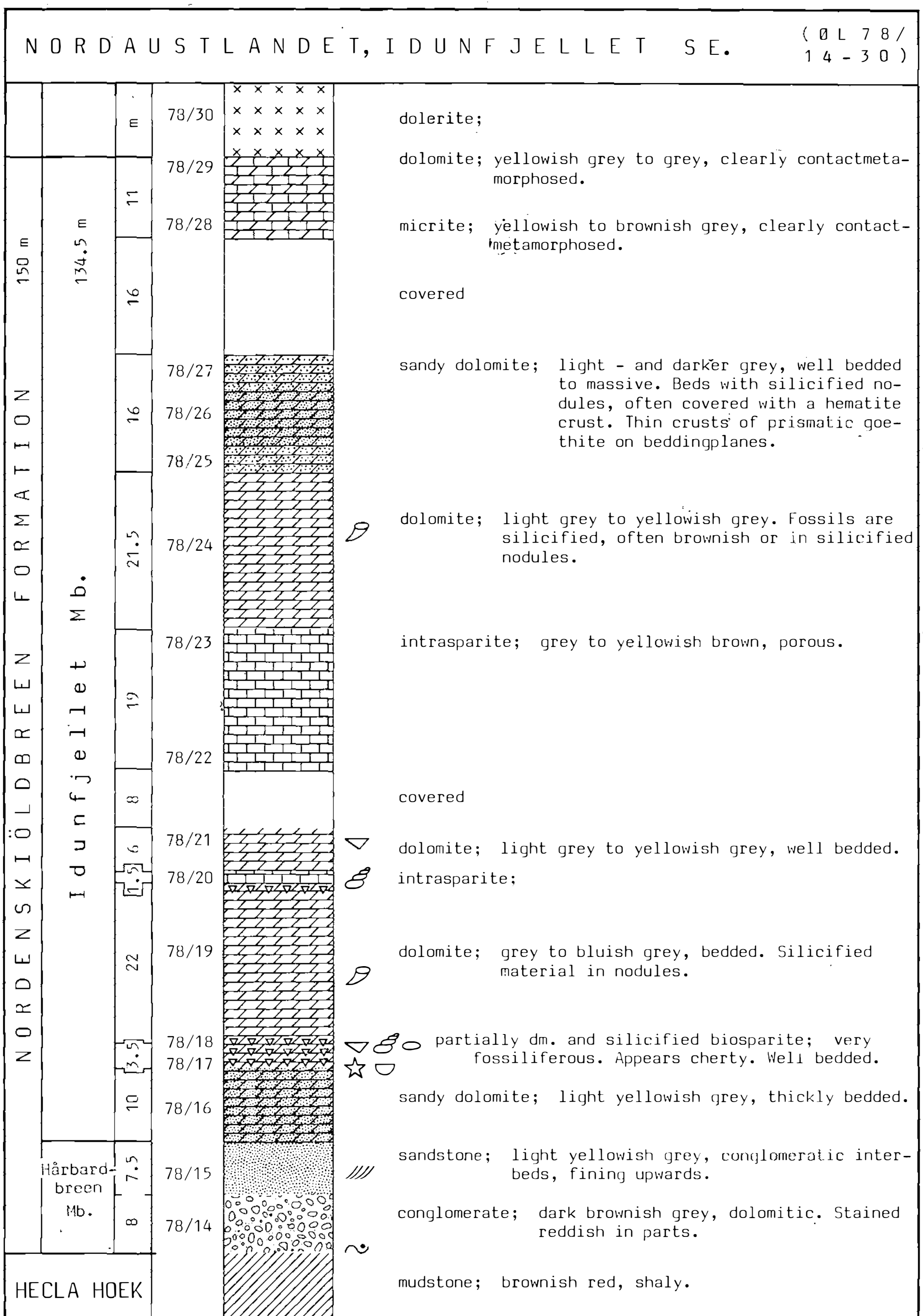

Fig. 3. *Idunfjellet section. Numbers beside the section refer to samples collected. Symbols of rock types and fossils seen in field, see legend Fig. 4.*

suggest that the Hårbardbreen Member is locally developed, very much dependent upon the topography of the underlying Hecla Hoek peneplain.

Idunfjellet Member

Type section: as for formation

Reference section: Zeipelfjella south.

The unit is 134.5 m thick, and the base is defined by the introduction of carbonate in the sequence. It is equivalent to the lower part of Lowell's (1968) Carbonate Member. The type section is found at Idunfjellet (Fig. 3), but the upper part is better exposed at Zeipelfjella south (Fig. 4). Lowell included all the sediments from here and up to the Kapp Starostin Formation in his Carbonate Member, a grouping which is not acceptable and must be discarded.

The lowermost 10 m of the Idunfjellet Member is a light yellowish-grey, well-bedded sandy dolomite (Table 1, sample ØL 78/16). Although the high carbonate (entirely dolomite) content of this rock gives a more fine-grained appearance than the underlying sandstone, the terrigenous quartz grains have

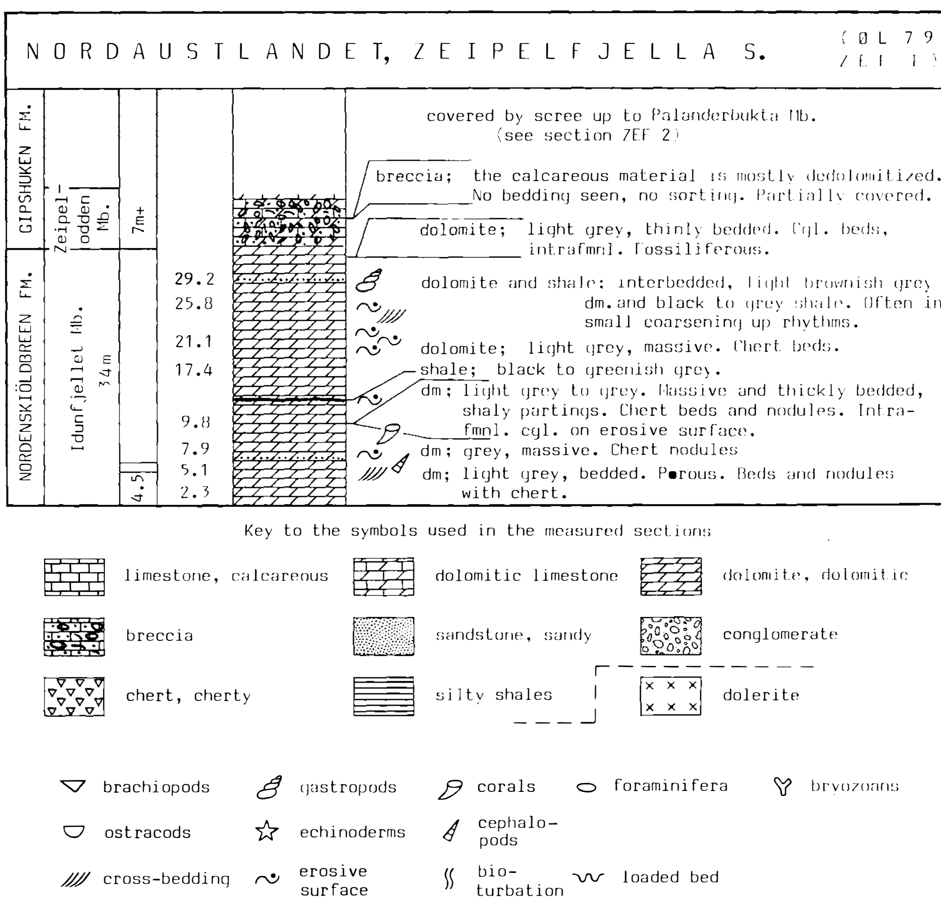

Fig. 4. *Zeipelfjella south section. Numbers beside the section refer to heights (metres above sea level) at which samples were taken. Symbols for rock types and fossils in all sections as shown.*

Table 1.

Microfacies analyses of samples from the Nordenskiöldbreen Formation at Idunfjellet dm. = dolomite, calc. = calcite, qz.gr. = quartz grains, foram. = foraminifera, cor. = corals, ech. = echinoderms. Dolomite crystals and grain size based on Ieighton and Pendexter (1961), i.e. crypto-, micro-, very fine, fine, medium and coarse grained/crystalline.

Sample ØL 78	Rock type	Textural components (%)										Dolomite mean/ largest rhomb size	Quartz mean/ larg. grain size
		dm.	calc.	qz. gr.	chert	skeletal grains					pores		
						total	foram.	cor.	ech.	indet			
30	dolerite												
29	calcareous dolomite	81	19									cryptg./micg.	
28	dolomitic cherty micrite	17	66		17							cryptg./fg.	
27	sandy dolomite	90	<1	6							3	cryptg./vfg.	vfg./fg.
26	sandy dolomite	67		24							9	cryptg./micg.	vfg./fg.
25	sandy dolomite	92	<1	7							<1	micg./fg.	vfg./fg.
24	dolomite	91	6		3	22		22			<1	micg./fg.	
23	intrasparite	<1	89		2						8	vfg./fg.	
22	intrasparite	9	85	1							5	vfg./fg.	fg.
21	dolomite	97	3									cryptg./vfg.	
20	intrasparite		100										
19	dolomite	100										micg./fg.	
18	dolomitic cherty biosparite	29	<1		68	7	5		1	1	1	cryptg./micg.	
17	dolomitic cherty biosparite	36	2		62	18	14		4			micg./mg.	
16	sandy dolomite	75		25								cryptg./micg.	vfg./mg.
15	sandstone	3		82	5						10	cg.	vfg./mg.
14	dolomite conglomerate	92		4							3	micg./micg.	vfg./mg.

the same grain size as those below. Above the sandy dolomite a very distinct 3.5 m thick unit of partly dolomitized and silicified biosparite (Table 1, sample ØL 78/17 and 18) occurs, and the chert content (about 65%) makes this rock very resistant to weathering. This sediment represents the first clear marine deposit in the succession, and its fossil content is highly important. Macrofossils like brachiopods, gastropods, and echinoderms are abundant, and microfossils have made it possible to date this horizon to the Upper Moscovian (see Palaeontology, p. 36).

These fossiliferous beds are sharply overlain by 78 m of calcareous sediments, with only occasional fossils. Chert nodules are abundant at some horizons. Individual beds usually consist of either calcite or dolomite, and mixtures of these minerals are found occasionally. A 16 m thick sandy dolomite appears 91.5 m above the base of the Idunfjellet Member (Table 1, sample ØL 78/25—27). Quartz content varies from 6% to 24% with a grain size similar to that found in the lowermost part of the member. Chert nodules are abundant, and silicification tends to follow certain horizons in well-bedded hostrock. Cherts are associated with crusts of hematite and thin layers of prismatic goethite in some beds at Idunfjellet.

The upper part of the succession at Idunfjellet is contact metamorphosed by the overlying dolerite. As the upper part of the Idunfjellet Member is better exposed in the southern part of the investigated area, at Zeipelfjella south (Fig. 4), the description of the uppermost beds is based on that section.

At Zeipelfjella south, the top of the Nordenskiöldbreen Formation is overlain by a breccia, interpreted as the lowermost member of the Gipshuken Formation, and it seems to be at this level in the succession that the dolerite has intruded the sequence at Idunfjellet, an assumption supported by observations at Hårbardbreen.

The section at Zeipelfjella south starts 34 m below the Gipshuken Formation, where it is dominated by dolomite (Fig. 4 and Table 2). Terrigenous quartz is found in all samples up to ZEF 1—25.8 (Table 2), exhibiting a natural continuation of what is found at Idunfjellet (Table 1, sample ØL 78/26 and 27). Other important features in this sequence are erosive surfaces with thin intraformational conglomerates and cross-bedded units. Dolomitization has destroyed most fossil fragments, but they seem to be abundant at certain horizons.

Chert nodules are common in the lowermost 22 m of this section at Zeipelfjella south (Fig. 4). They could be indications of originally evaporitic environments as they are similar to gypsum/anhydrite-nodules which occur elsewhere in Svalbard (Lauritzen 1977); however, no trace of sulphates is found today.

GIPSHUKEN FORMATION

Type section: Zeipelodden

Reference section: Zeipelfjella west

The formation is 121 m thick, and a lower member can be clearly distinguished, here defined as the Zeipelodden Member. This formation is heavily

Table 2.

Microfacies analyses of samples from the Nordenskiöldbreen and Gipshuken Formations at Zeipelfjella south. Abbreviations, see Table 1.

Sample ØL 79 ZEF 1	Rock type	Textural components (%)									Polomite mean/ largest rhomb size	Quartz mean/ largest grain size
		dm.	calc.	qz. gr.	chert	skeletal grains				pores		
						total	foram.	algae	indet			
29.2	dolomite	93	1			37		+	37	7	cryptg./fg.	
28.5	dolomite	88	8			14	+	?	14	4	cryptg./micg.	
25.8	dolomite	96		1			+			4	cryptg./micg.	vfg./vfg.
21.1	dolomite	80	2	4	1					15	micg./c.micg.	c.micg./vfg.
17.4	dolomite	91	4	2						3	micg./c.micg.	vfg./fg.
9.8	dolomite	95		5							micg./c.micg.	vfg./fg.
7.9	dolomite	94		2					3	1	micg./fg.	c.micg./fg.
5.1	dolomite	93		4			+	+		2	micg./vfg.	fg./mg.
2.3	dolomite	91		2						7	vfg./fg.	vfg./fg.

covered by scree in the area, but good exposures are found where the sections are measured.

Zeipelodden Member

Type section: as for formation

This member is 8 m thick and contains a mixture of lithologies, limestone breccias occurring together with finely laminated algal limestones. Irregular bedded horizons, where bedding is found, are weathered into up to 1 m high caverns, a property which makes this unit easily recognizable even from a distance. Samples from this unit (Table 3, samples ØL 79 **ZEO** 1—120^{I} and 120^{II}), show that the sediments are highly porous, and that calcite is the most important mineral component. There is, however, clear evidence of dedolomitization, a fact also registered in corresponding beds from the Lomfjorden area by Lauritzen and Worsley (1975).

Above the Zeipelodden Member, 17.5 m of beds are exposed towards the top of the mountain at Zeipelodden (Fig. 5); calcite is the dominant mineral with small amounts of terrigenous quartz. This part of the succession is dominated by well bedded, mostly fine-grained limestones, and erosive surfaces are common, often with intraformational conglomeratic beds. Finely laminated algalmicrites are found, associated biomicrites and biosparites.

Dolomitization has not destroyed the fossil fragments in this part of the succession, althoug macrofossils were not found, except for the algae. Good exposures of the rest of the Gipshuken Formation are not found, because scree

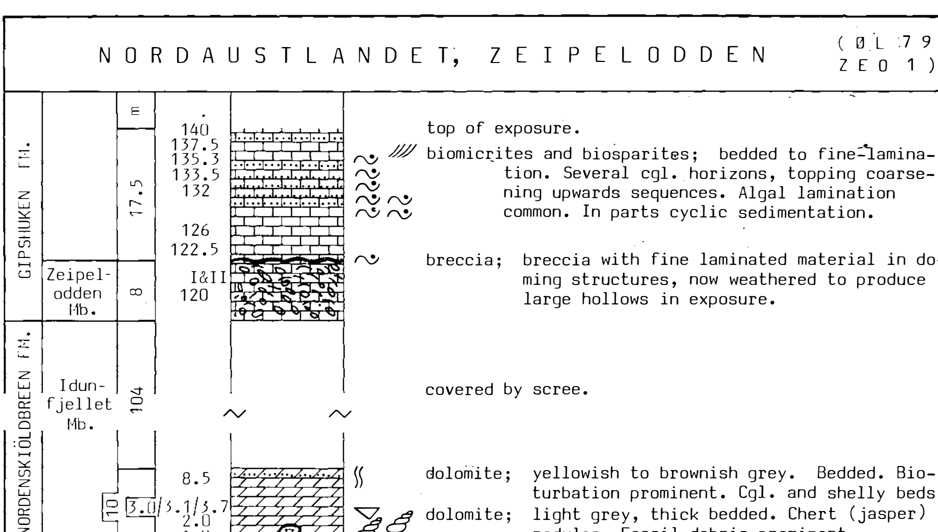

Fig. 5. *Zeipelodden section. Numbers besides the section refer to heights (metres above sea level) at which samples were taken. Symbols, see Fig. 4.*

Table 3.

Microfacies analyses of samples from the Nordenskiöldbreen and Gipshuken Formations at Zeipelodden. bra. = brachiopods, gast. = gastropods : key otherwise as in Table 1.

Sample ØL 79 ZEO 1	Rock type	Textural components (%)												Dolomite mean/ largest rhomb size	Quartz mean/ largest grain size
		dm.	calc.	qz. gr.	chert	skeletal grains							pores		
						total	foram	ech.	algae	bra.	gast.	indet			
140	neomorph biomicrite		95	3	2	20		20							c.micg./fg.
137.5	neomorph biomicrite		99	<1		20		20							micg./c.micg.
135.3	partly neom. biosparite		99	1		19		19							micg./vfg.
133.5	partly neom. silty algalmicrite		92	8					+						micg./vfg.
132	partly neom. micrite	2	97	1										micg./micg.	micg./micg.
126	micrite	<1	98	<1		<1						<1		micg./micg.	micg./micg.
122.5	algalsparite	12	81	1	1	37			37				5	micg./micg.	c.micg./c.micg.
120II	partly dedolom. algalsparite	10	67		<1	<1			+				23	c.micg./mg.	micg./vfg.
120I	dedolom. lmst.breccia	<1	89	<1	<1								10	fg./mg.	micg./vfg.
8.5	dolomite	90				1							10	vfg./fg.	
3.7	dolomite	96			<1	<1		<1		<1			3	micg./vfg.	
3.1	dolomite	83	1		3	3	3						13	micg./fg.	
3.0	dolomite	94	2		<1	22	17	1	+	3	<1	<1	4	micg./fg.	
2.0	dolomite	89				<1	?				+	<1	11	micg./fg.	
1.0	dolomite	92	1				?	?					7	micg./fg.	

conceals these beds, but at Zeipelfjella west (Fig. 6) some exposures are found in the upper part of the formation. The beds there consist of greyish to brownish, thickly bedded medium-grained dolomite, in which are found scattered nodules of light chert with some calcite. These nodules are also developed similarly to sulphatic nodules from corresponding beds elsewhere in Svalbard, but not even here were traces of gypsum or anhydrite found.

KAPP STAROSTIN FORMATION

Type section: Zeipelfjella west

The formation is 141 m thick at Palanderbukta, and two members can be distinguished. The lower Vøringen Member can be correlated with corresponding beds elsewhere on Spitsbergen, while the Palanderbukta Member is defined here. Silicification is extensive throughout the formation, but individual units (e.g. the Vøringen and Palanderbukta Members) are dominated by biosparites. Likewise, minor limestone bodies, nodules and beds are found in the more silicified parts of the formation, and my studies have been directed to these limestones.

Vøringen Member

Type section: as for formation

This unit is 9 m thick at Palanderbukta, easily distinguishable, resting with a clear erosive contact on the underlying Gipshuken Formation (the Vøringen Member was not clearly identified by Lowell (1968) on Nordaustlandet). The Vøringen Member is very well exposed.

This unit consists of mainly sandy, medium to coarse-grained biosparites (Table 4, sample ØL ZEF 2—137), but conglomeratic horizons and shaly partings are found. Erosive surfaces are numerous, and cross-bedding and bioturbation are observed in the section. Fragments of coal are found in loose blocks in the area. Although no coals were found in the exposed section, these blocks are most likely from the lower part of the Vøringen Member, as similar coal fragments are found in corresponding beds in the Isfjorden area in central Spitsbergen. T.S. Winsnes (pers.comm.) confirms that coal fragments are found in the basal beds of the Vøringen Member at Nordaustlandet. The unit is extremely fossiliferous, and large brachiopods and bryozoans dominate.

Above the Vøringen Member there is an abrupt lithological change and blueish grey to white cherts dominate the overlying 37.5 m of the section. However, relicts of more calcareous rocks and pure limestones, some very fossiliferous, occur either in well defined beds or in isolated nodules. The uppermost 6 m of these beds contain intraformational conglomeratic horizons and numerous erosive surfaces.

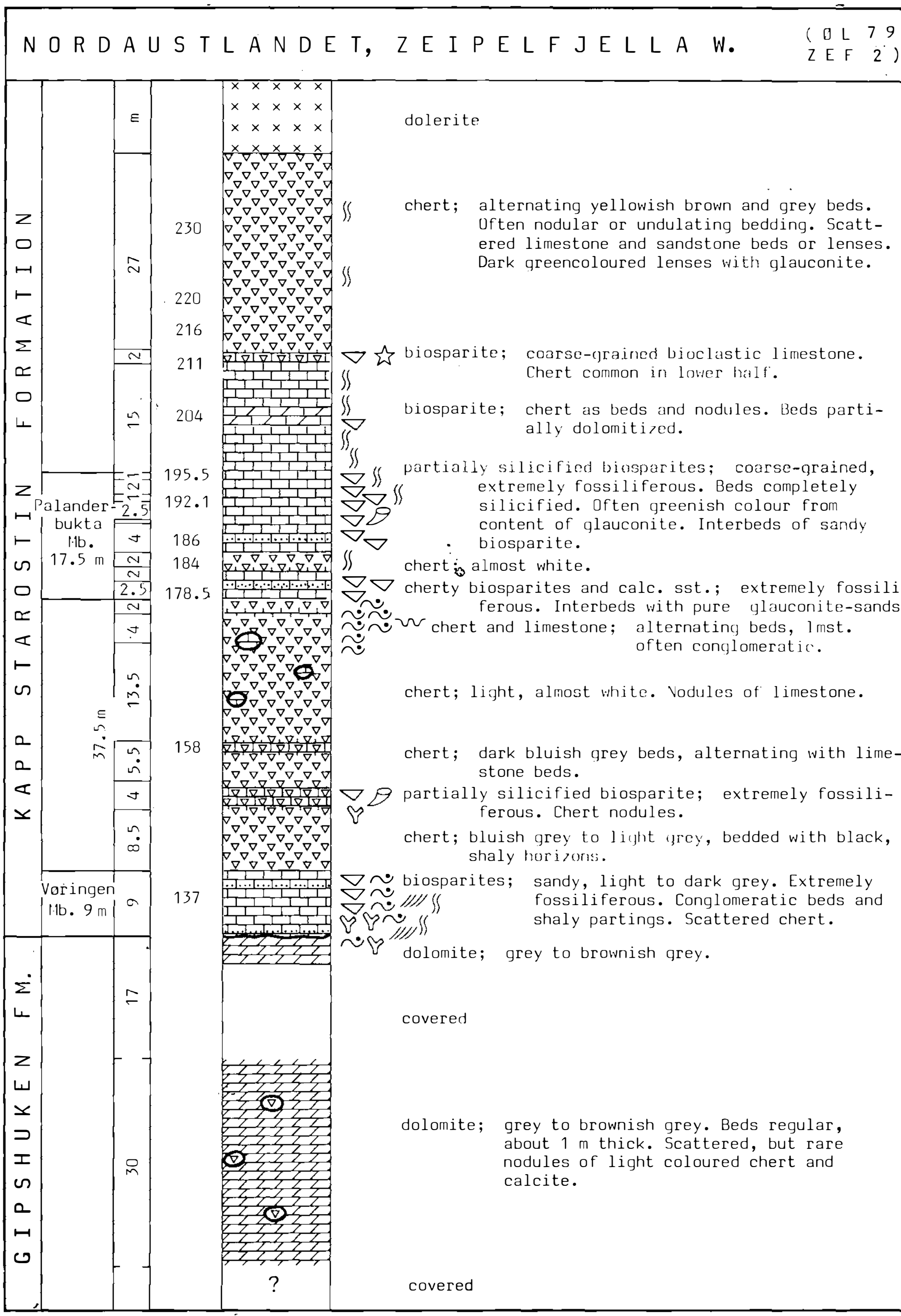

Fig.. 6 *Zeipelfjella west section. Numbers beside the section refer to heights (metres above sea level) at which samples were taken. Symbols, see Fig. 4.*

Palanderbukta Member

Type section: as for formation

This member is 17.5 m thick, and the base of this unit is found marked by a sharp lithological break at 46.5 m above the base of the Kapp Starostin Formation. This unit is also limestone dominated, and it is extremely fossiliferous. Large brachiopods dominate, though corals are also found. The unit consists mainly of sandy biosparites with minor cherty biosparite and pure chert beds. An almost white 2 m thick chert is found in the lowermost part of this unit.

The Palanderbukta Member often has a characteristic green colour caused by the presence of glauconite, and some beds consist of almost pure glauconite sand.

More calcareous sediments are also found above the Palanderbukta Member, but a marked change in lithology occurs at 64 m above the base of the formation (Fig. 6). From this level and upwards, 17 m of biosparites are found, often cherty (Table 4, sample ØL 79 ZEF 2—204). Fossils are found in this part, but they are not common. Dolomite occurs in samples from this part of the succession, but seems to be of minor importance in the Kapp Starostin Formation. The chert content is highly variable, and mostly restricted to isolated nodules and beds. The dominance of limestones ends 81 m above the base of the formation, with a 2 m thick bioclastic limestone, rich in brachiopods and echinoderms (Fig. 6). Above this bed, chert dominates.

At Zeipelfjella west (Fig. 6), chert found in the upper 27 m of the exposed section is overlain by dolorite; a further 33 m of chert exposed a little to the north in the same mountain is, however, directly overlain by Triassic siltstones and silty shales. The cherts are bedded, although the bedding is often irregular. Light, yellowish grey cherts alternate with more pure grey beds. The more brownish colour is probably caused by relicts of calcareous material. Lenses of pure limestones (Table 4, sample ØL 79 ZEF 2—220 and 230) and scattered green lenticular bodies of glauconite sand are common. Sandstones are also found in beds and lenses. Voids with crystals of secondary calcite and quartz seem to be common in the uppermost 15 metres of the section at Zeipelfjella west, where these beds are capped by a dolerite.

Palaeontology

Previous fossil finds from the Upper Palaeozoic succession of Nordaustlandet have been restricted to macrofossils which have not made possible any precise dating of the succession. Lowell (1968) was aware of this, and he therefore presented three alternative possible ages for the lowermost part of the succession. He noted that fusulines were lacking in these beds; fusulines were, however, found in my studies, and supply clear evidence for the age of the base of the succession.

Dr. J.E. Whittaker (British Museum of Natural History) examined samples ØL 78/17 and 18 from the base of the section at Idunfjellet (Fig. 3) and kindly sent me a preliminary report on which the following comments are based, but

Table 4.

Microfacies analyses of samples from the Kapp Starostin Formation at Zeipelfjella west. glauc. = glauconite, bryoz. = bryozoans, spic. = sponge spicules. Otherwise, key as in Table 1.

Sample ØL 79 ZEF 2	Rock type	Textural components (%)											Quartz mean/ largest grain size
		chert	calc.	dm.	qz. gr.	glauc.	skeletal grains					indet	
							total	bra.	bryoz.	ech.	spic.		
230	rexd. intrasparite		100										
220	rexd. intrasparite		100										
216	cherty rexd. intrasparite	40	55	5	+								c.micg./fg.
211	rexd. biosparite	3	97							+			
204	cherty biosparite	61	15	20	3		35					35	c.micg./fg.
195.5	cherty biosparite	66	34		+		41	12		<1	26	2	fg./fg.
192.1	cherty biosparite	75	25				48	<1	10	25	+	12	
186	sandy biosparite		89		11		13	1		10		2	fg./cg.
184	chert	98	<1		1						+		fg./fg.
178.5II	calcareous sandstone		45		55		9	9		<1			vfg./mg.
178.5I	cherty biosparite	62	27		11		42	16	11	9		6	fg./mg.
158	cherty biosparite	73	27								+		
137	sandy biosparite		68	2	29	1	23	9	4	<1		9	fg./cg.

more detailed studies on this material are in progress (Lauritzen & Whittaker, in prep.).

Sample ØL 78/17 contains abundant fusulines which all have a primitive fusulinellid wall, and belong to the Fusulininae as defined by Loeblic and Tappan (1964). Specimens may be assigned to either *Eofusulina* or *Paraeofusulina,* two genera virtually restricted to the Moscovian, the latter to the upper part of the stage (Ross 1973). Two species close to this material are *Eofusulina* cf. *triangula* (Rauzer & Belyaev), already recorded from Spitsbergen by Forbes (1960) and *Paraeofusulina trianguliformis* Putrja, previously recorded in the Arctic from NE Greenland. Ross and Dunbar (1962) considered the latter to be indicative of the early Moscovian (Kashirian). The second type of fusuline present is a rare *Pseudostaffella* or *Neostaffella,* but unfortunately only tangential sections have been found. Of non-fusuline foraminifera present in the sample, only rare specimens of *Bradyina* ssp. are of any significance. One large specimen is probably *Bradyina magna* Roth and Skinner, and a smaller form might be referred to *Bradyina sarmarica* Reitlinger, originally described from the late Moscovian of the Russian Platform (Reitlinger 1950).

Sample ØL 78/18 has only rare fusulines and is instead characterised by two large species of *Bradyina.* The first one appears to be akin to forms such as *Bradyina nautiliformis* Møller, or *Bradyina magna* Roth and Skinner, both characteristic of the Moscovian (Reitlinger 1950). Of the associated fauna in the sample, such palaeotextulariids as *Tetrataxis* ssp., rare fusulines (probably the same species of *Paraeofusulina* as in sample ØL 78/17), and smaller species of *Bradyina* are found. Based on the foraminifera found in the rocks, both samples are of Middle Carboniferous, Moscovian age.

Dolerite

The dolerites most likely occur as sills, although they always form the top of exposures and no overlying sediments have been seen. The thickness of the sills varies from 30—50 m and they intrude all Upper Palaeozoic formations as well as the lower part of the Triassic succession.

At Idunfjellet euhedral garnet crystals (andradite, B. Jensen, pers.comm.) occur in vertical joints within the dolerite, but not in the adjacent contact metamorphosed calcareous rocks.

Discussion

There are no signs of Devonian rocks on Nordaustlandet. The Hecla Hoek sediments of the Wahlenbergfjorden area consist mainly of dolomites, mudstones and quartzites (see also Sandford 1963), and the whole sequence was folded and eroded prior to the Moscovian transgression which initiated deposition of the Upper Palaeozoic succession. The age of the lower units of the Upper Palaeozoic sequence on Nordaustlandet has been debated, because of the lack of diagnostic fossils in these lower beds. Such fossils have

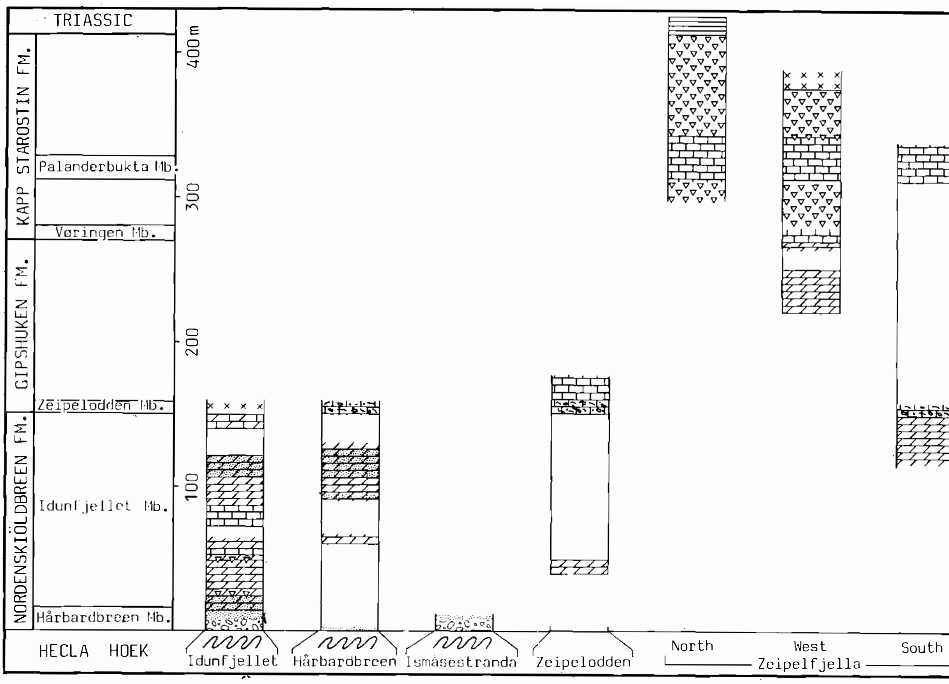

Fig. 7. *The section from the Wahlenbergfjorden area, on which the stratigraphical conclusions are made in this paper. For details, see the individual sections.*

now been found (see Palaeontology, p. 36) and the age of the lowermost fossil-bearing beds can therefore be ascertained. Prior to this investigation, most papers dealing with these beds called them "Carboniferous and Permian rocks", but Cutbill and Challinor (1965) placed the Hardbardbreen Member in the Artinskian, suggesting a total absence of Carboniferous and lowermost Permian units. Lowell (1968) accepted this interpretation partly on the basis of a personal communication from Cutbill stating: "the carbonate rocks above the Hardbardbreen are very similar to those in the upper part of the Gipshuken Formation in northern Vestspitsbergen (now Spitsbergen); they are not closely similar to the Tyrellfjellet or Cadellfjellet members of the Nordenskiöldbreen Formation of the same area".

Even though Lowell accepted that only Permian beds were present, his paper shows that he was not totally convinced, and therefore presented other possibilities, ending his discussion with: "For convenience in presentation the scheme of Cutbill and Challinor is followed, but readers should be aware of alternatives" (Lowell 1968, p. 351). My interpretation is presented in Fig. 2.

The transgression mentioned above, appears to have been contemporaneous with that described from the central parts of Spitsbergen and from the Ny Friesland area. (In Ny Friesland, Cutbill (1968) found an Upper Moscovian fauna on the east side of Lomfjorden, in limestones a few metres above the Svenbreen Formation).

The Hårdbardbreen Member, which is here redefined, forms the base of the Upper Palaeozoic sequence in this area. Lowell (1968, p. 350) states: "the

Hardbardbreen sandstones seem clearly to have been derived from a sea transgressing a granitic source, probably the pink granodiorite mapped by Sandford at the head of the Wahlenbergfjorden and extending northward to Rijpfjorden".

I disagree with this statement as my own investigations indicate that the sediments of the Hårdbardbreen Member are locally derived. The sea which transgressed the Hecla Hoek sediments mentioned above, eroded these same sediments and redeposited them shortly afterwards. The basal conglomerate in this member contains clasts of dolomite and red mudstones at Idunfjellet, and both these rock types are found within a few hundred metres from where they are found redeposited today. Both composition and texture of the conglomerate reveal that it was locally derived. This dolomite conglomerate is not developed on the southern side of the fjord, and instead quartzitic material with some clasts of red mudstone is found. Also here the rock seems to have been locally derived. Fining-upwards in the sandstone suggests continued transgression and submergence of the high energy beach and intertidal sediments of the Hårbardbreen Member.

Lowell (1968) defined his Carbonate Member at the introduction of carbonate in the succession. The Carbonate Member thus included both Nordenskiöldbreen and Gipshuken Formation equivalents, although Lowell thought that only the latter was present. Lowell's member grouping is not accepted here and a new unit, the Idunfjellet Member, is introduced for its lower part.

The Idunfjellet Member represents in part shallow marine to open shelf environments, with input of terrigenous quartz in the lower and upper parts. Within this member the first clear fossiliferous marine beds are found, and these fossils have been the key to the age of the succession.

In the upper part of the Idunfjellet Member, there is evidence of shallowing, with numerous erosive surfaces and intraformational conglomerate beds. Cross-bedding sets with diametrically opposed directions suggest tidal influence on sedimentation. Nodules and beds of chert, here interpreted as possible remnants or pseudomorphs of

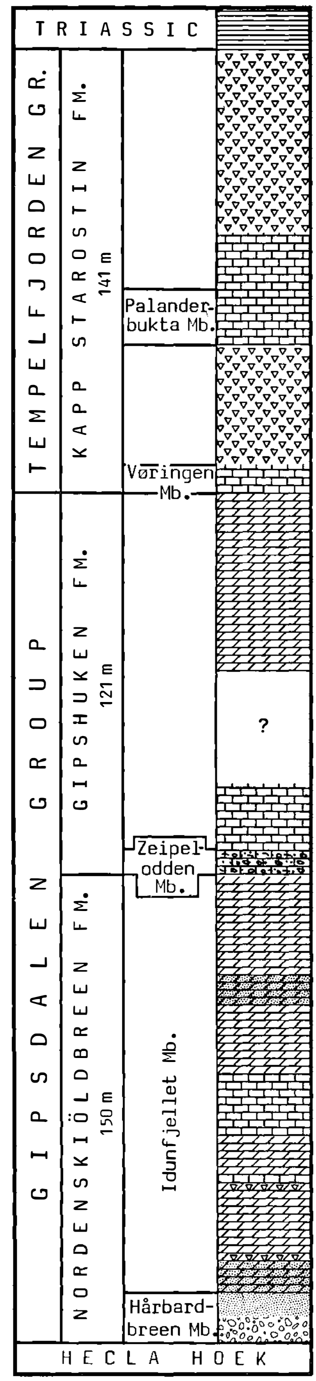

Fig. 8. *The composite section through the Carboniferous and Permian beds of the Wahlenbergfjorden area, comprising 412 metres. Symbols, see Fig. 4.*

sulphates, may even indicate supratidal conditions within this member. Micritic and shaly material points to a low energy situation in certain beds, a situation found in protected tidal flats.

The Gipshuken Formation starts with a breccia or a brecciated unit, here defined as the Zeipelodden Member, a unit also recognized in corresponding beds from Ny Friesland, described by Cutbill (1968) and Lauritzen and Worsley (1975). The sediments within this unit are rather complex, with a mixture of finely laminated limestones and breccia. The cavernous weathering has affected original hemispheroids of algal buildups, often a metre high and with a diametre of two to three metres at the base. Algal mats and crusts are positively identified within these structures. A mixture of white chert and calcite, here interpreted as remnants of sulphates, is found within some of the hollows in this rock. Dedolomitization has evidently taken place in this unit.

The Zeipelodden Member seems to represent intertidal to supratidal environments, characterized by the growth of algal crusts and mounds, with episodes with formation of evaporites. These evaporites were partly dissolved in periods with flooding, resulting in the formation of solution breccias.

The beds above the Zeipelodden Member are well-bedded and rest with a marked erosive contact on the top of the breccia; these beds contain more micritic material than seen below. The beds exposed at Zeipelodden exhibit a cyclic trend, with fine-grained algal-laminated sediments repeatedly interbedded with conglomeratic horizons. Fining-upwards is the normal trend in these rocks, but coarsening-upwards episodes are also traced. The sediments are interpreted as representing a lagoonal environment with algae and echinoderms. The conglomeratic beds may represent tidal channel infills within this environment.

Even though most of the overlying beds from this level and up to the Kapp Starostin Formation are poorly exposed, it is obvious that some of the dolomites exposed at Zeipelfjella represent shallow marine conditions. Their content of chert nodules, here again interpreted as remnants of evaporites, suggests that supratidal depositional environment may have been present, but nothing like the thick evaporite beds of central Spitsbergen have been seen.

The Kapp Starostin Formation rests on a clearly eroded surface of the Gipshuken Formation in the section exposed at Zeipelfjella. The lowermost unit, the Vøringen Member, is clearly recognized, even though Lowell (1968) starts his description of the Kapp Starostin Formation with a unit "probably equivalent to the Vøringen Member". The development of this unit on Nordaustlandet is very similar to that seen elsewhere in Svalbard.

The Vøringen Member is a transgressive shallow marine and extremely fossiliferous unit. It most likely represents transgressive shore line deposits. The content of coal fragments in the lower part could either indicate the presence of an established flora in the area prior to the transgression, or the coal could be reworked clasts of older in situ coals exposed nearby. Such coal fragments are also found in the Vøringen Member at Tempelfjorden in central Spitsbergen. No older coalbearing rocks are known on Nordaustlandet. The

Vøringen Member in this area represents transgressive fossiliferous carbonate banks, drowned during the deposition of the overlying sediments.

The sequence above the Vøringen Member is now mostly represented by cherts, and these rocks are interpreted as open shelf sediments. Units with silicified biosparites show that the deposition was at times faster than the basinal subsidence or migrating bioclastic banks on the shelf. Towards the top of this chert-dominated unit, erosive surfaces and intraformational clasts of limestones in conglomeratic beds are found. The limestone clasts show that the limestones must have been early cemented, since erosion and transport were possible.

The Palanderbukta Member is also extremely fossiliferous, and represents another shallow marine event in the Kapp Starostin Formation. It contains large brachiopods as found in the Vøringen Member, but lacks the bryozoans. Greensand and the high content of glauconite indicate transportation from deeper waters with redeposition in the Palanderbukta Member. The unit is interpreted as shallow marine carbonate banks, but differences in sediment types within this unit indicate a subsiding basin with deposition of new fossiliferous carbonate banks after the burying of their predecessors.

A high content of glauconite within the Palanderbukta Member, draws attention to the Selander Suite of Burov et al. (1964). Ustritskii (1977, English transl.) states: "The Selander Suite unites the youngest of all Palaeozoic deposits found on Spitsbergen". These beds were correlated to the Upper Permian deposits recorded from Barentsøya by Burov et al. (1964), but Lock et al. (1978) proposed the informal name of "Kapp Ziehen Formation" for all the Permian strata on both Barentsøya and Edgeøya, until such time where their relationship to the Kapp Starostin Formation in the rest of Spitsbergen and Nordaustlandet is better known.

My own investigations from Nordaustlandet do not agree with Burow's view that the glauconite-rich beds are the youngest of all Palaeozoic deposits, because in the Wahlenbergfjorden area the green beds are overlain by carbonate rocks and cherts. Although glauconite is found in the upper part of the formation, it does not dominate.

Above the Palanderbukta Member, subsidence in the basin was prevailing, and more micritic material was found within the sediments. Biosparitic beds indicate the influence of wave, possibly storm, activity. A last bioclastic horizon with echinoderms and brachiopods is found before cherts dominate the upper part of the Kapp Starostin Formation. These cherts are often spiculitic, and it must be assumed that deeper water was prevailing in this area throughout the rest of the Permian period. As elsewhere in Svalbard the nature of the Permian/Triassic boundary is obscure.

Conclusion

The lowermost part of the Upper Palaeozoic succession in the Wahlenbergfjorden area is clearly transgressive. Fossiliferous beds above the basal member have made it possible to date these beds to the Upper Moscovian, showing that this transgression took place simultaneously with the one described from Ny Friesland and the central part of Spitsbergen. Most of the 142 m thick succession is calcareous and is deposited in shallow marine environments, but horizons with chert nodules and beds, here interpreted as remnants of evaporites, suggest periods with intratidal deposition. Towards the end of the Permian period, spiculitic cherts suggest a further subsidence and deepening of the basin. The nature of the boundary between the Palaeozoic and Mesozoic sediments could not be studied in the area investigated.

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Author's address:
Norsk Polarinstitutt
Rolfstangveien 12
1330 Oslo Lufthavn
Norway

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A.S JOHN GRIEG